

# Selected design issues of a dedicated facility for generic QCD studies

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QCD, even if presently out of fashion, deserves a dedicated, generic research program providing new challenges for the theory and aiming at understanding hadronic matter and vacuum in terms of quark and gluon degrees of freedom. Such a research program needs a dedicated facility to re-address basic questions which remain unanswered and to open new vistas.

## 1. Introduction

QCD is the theory of strong interactions. At distances, which are sizeably smaller than the size of hadrons, interactions of quarks and gluons, the basic degrees of freedom of the theory, are precisely controlled by perturbative calculations. At distances comparable to the size of hadrons, the basic degrees of freedom and the symmetries of the theory are hidden and perturbative methods are no longer valid. Understanding the relationship between the quark-gluon and the hadronic (nuclear) degrees of freedom is the most challenging issue in the domain of strong interactions.

The consequences of non-abelian properties of QCD can be only partially accessed by the lattice calculations. This is both due to the limitation of the power of the available computers and, more importantly, due to the very nature of numerical methods. Further progress in understanding the relationship between quarks and gluons and their effective collective modes (hadrons and nuclei) is thus bound to be driven by a generic experimental program, which needs to develop its novel femto-technology tools, allowing not only for observing, but also for manipulating quarks and gluons in various QCD media.

Leptons and nuclei are indispensable for development of such tools. Deciphering high energy collisions of nucleons and nuclei in terms of basic quark-gluon processes is difficult. Collisions of nucleons and nuclei with leptons could play a role of the Enigma machine capable of decoding the p-A and A-A collision data. Lepton beams resolve interactions of charged con-

stituents of hadronic matter with precisely controlled resolution power not only at small but also at large (confinement scale) distances. They can thus be considered as surgery tools for effective filtering of various distance scales involved in the interactions and for controlling the initial configuration of quark degrees of freedom. In large coherence-length processes, nuclei provide effective means to tune the projected densities of quark-gluon systems and/or to tune the effective strength of colour forces. Conversely, in small coherence-length processes, they play a role of variable-length-absorbers of quarks and gluons. Last but not least, nuclei can be used as femto-detectors to observe the space-time structure of interactions of quarks and gluons. Polarization of leptons, protons and light ions is vital for studies of the spin structure of various QCD media.

Following the discovery of quarks and gluons, a large number of experiments have been performed to understand their interactions. A future, generic QCD research program at a dedicated facility, providing collisions of large-intensity and atomic-number-tunable ion beams with large-intensity polarized beams of protons and electrons, could extend the frontier of understanding in a significant way. It requires a research and development effort on beam cooling techniques and on high intensity polarized electron sources. The progress in collider capacity has to be matched by a novel detector design providing a full reconstruction of all particles produced in collisions of electrons, protons and nuclei.

Such a QCD-dedicated program represented, in

my view, the best long term research option for the HERA collider [1], underlying both the specificity and the complementarity of HERA with respect to Tevatron and LEP and RHIC. This option was considered, however, less attractive than the presently realized high-lumi option and it was abandoned. The eRHIC project [2] aiming at adding an electron linac to the existing BNL facilities revived and extended the scope of such a program. Building the electron linac at the BNL site have numerous advantages. For example, a use can be made of the available 12 o'clock collision zone of the RHIC collider as a site for the future multipurpose detector. Such a detector could be optimized not only for measuring collisions of protons and nuclei with electron but also for measuring collisions of polarized protons as well as collisions of protons with nuclei.

The eRHIC design have been discussed at several workshops and conferences. In this short note I sketch the basic criteria specifying the ep (eA) collider parameters and present the first design trial of a dedicated full event detector for the eRHIC project. More details can be found e.g. in talks and lectures on this subject (the most recent ones can be found in [3]).

## 2. Optimizing the ep (eA) collider parameters

### 2.1. Collision Energy range and tunability

At high energy frontier, proton-proton and proton-nucleus collisions provide already an adequate environment to study short-distance interactions of quarks and gluons. The low- $x$ , large coherence-length spin- and momentum-structure of nucleons can be resolved using intermediate energy electrons. For example, a 10 GeV electron beam colliding with a 100 GeV protons (nuclei) resolves the deep inelastic structure of the target down to  $x_{Bj} = 10^{-3}$ . At this  $x_{Bj}$  value the coherence-length exceeds already by one order of magnitude the size of heaviest nuclei allowing for a sufficient lever arm for extrapolations to even smaller  $x_{Bj}$  values.

The ep (eA) centre-of-mass collision energy range optimal for covering both the perturbative QCD region and the distance scales rele-

vant for hadronic matter such as the proton radius -  $R_p$ , nucleus radius -  $R_A$ ,  $1/\Lambda_{QCD}$ ,  $1/m_p$  is  $\sqrt{s} = 10 - 100$  GeV. The above energy span provides an optimal resolution range of the electron probe both in the transverse and in the collision (light-cone) direction. The low energy limit can be approached in parasitic fixed target collisions of the electron beam and thus can be moved above 10 GeV. Tunability of the beam collision energy is indispensable to filter out processes mediated by the transverse and the longitudinal virtual photons and is vital in understanding quark and gluon energy loss in various QCD media.

### 2.2. Ratio of lepton and nucleon/ion beam energies

Choosing the ratio of the proton (ion) to electron beam energies in the range 10-20 facilitates, in particular at the highest centre-of-mass energy, various aspects of the full event detector design. It assures both a good reconstruction quality and an efficient triggering of deep inelastic scattering events over the full  $x_{Bj}$  range. In addition, such a value of the beam energy ratio allows for an early decoupling the electron and of the proton (ion) beam optics, thus simplifying the design of the electron beam insertion. Last but not least, it permits operating high electron currents with controllable level of synchrotron radiation at the interaction point.

### 2.3. Charge and polarization of the electron beam

While highest and precisely controllable polarization of the electron and of the proton (light ion) beam is indispensable, a possibility of switching from electron to positron beam is of secondary importance. A majority of QCD processes leading to the charge asymmetries can be investigated by looking at spin asymmetries.

### 2.4. Choice of ion species

It is mandatory to collide electrons with heavy ions in order to maximize the nuclear medium effects and with lightest ions (e.g. deuteron) in order to study proton/neutron flavour asymmetries. In addition, it is highly desirable to cover uniformly the A-range on the  $A^{1/3}$  scale. Isoscalar ions should be preferably chosen, especially if the

collider compaction factor will permit simultaneous storing of two, isoscalar ion bunch-trains.

## 2.5. Luminosity

While highest achievable luminosity  $L * A \approx 10^{33} [cm^{-2}s^{-1}]$  is necessary for high precision measurements of spin asymmetries, for studies of exclusive and semi-exclusive processes, for rare fluctuations of nuclear densities and for the  $x > 1$  physics, there exist a vast inclusive physics program, which can be executed already at the luminosity, which is three orders of magnitude smaller than that quoted above. This creates an opportunity to consider the collider/detector project as evolutive, containing several open scenarios. Such a flexibility allows, for instance, for running at lower luminosities at comfortable  $\beta^*$  to study the electron, proton and ion fragmentation processes.

## 2.6. Beam parameters at fixed luminosity

It is desirable to minimize beam emittance rather than  $\beta^*$  at the Laslet and at the beam-beam tune shift luminosity limits. As a thumb rule the beam divergences at the interaction point should be kept largely below the level of  $P_{Fermi}/P_{Beam} = 5 * 10^{-4}$  for unambiguous identification of interacting nucleons with respect to spectator ones. In order to assure efficient triggering over the full  $x_{Bj}$ -range an emphasis has been put on cleanness of the beams, i.e. on the smallest possible halo of “out-of-bunch” particles.

## 2.7. Interaction Point geometry

Merits of the proposed range of collision energies, of the beam energy ratio and of using electron linac rather than circular machine are clearly visible while designing the interaction point geometry. In the configuration discussed above a clash between the magnetic lattice of the electron beam insertion and that of the proton (ion) beam can be largely avoided. In the limit of small ratio of electron to proton (ion) beam energies the electron insertion magnet causes only residual distortion of the proton (ion) beam trajectories. At small electron beam energy, it can be placed in the vicinity of the beam crossing zone and used as a momentum analyzer of particles produced at small angles while avoiding severe constraints related to effective masking of synchrotron radiation.

The layout of the interaction point geometry is greatly simplified if pre-polarized electrons are accelerated in a linac with no need for a spin rotation.

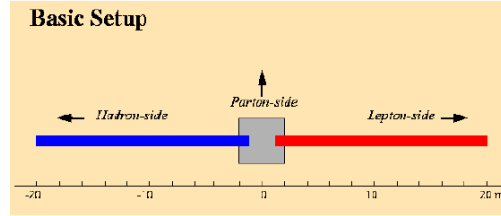


Figure 1. The detector geometry.

## 2.8. Three beams collider

The RHIC collider provides beams of ions and polarized protons, which cover fully the optimal energy range for the future ep (eA) collider (lower energy ion and proton beams can be stored at RHIC if cooled by a low energy electron beam). Thus, the Brookhaven National Laboratory turns out to be a cost effective site to conduct the future ep (eA) research program in close synergy with the present RHIC pp, AA and pA programs. An ambitious but extremely interesting scenario is to design the IP12 collision point as a collision point of 3 beams. In such a scenario one of the ion (proton) beam or the electron beam is guided in and out of the beam-beam collision zone, within a common beam tube, allowing for measuring ep, eA, pp, and pA collisions in the same region in a common full event detector. The ep (eA) collisions could thus be observed with no interference with the ongoing RHIC program. More importantly, a precise relative studies of medium-dependence of basic QCD processes can be made by using the same detector for ep, eA, pp and pA collisions. The collider parameters discussed

above, in particular the particular the choice of the range of electron energies with respect to the energies of RHIC beams facilitate such a design.

### 3. Full event detector - selected design issues

The full event detector has to provide measurements of all particles produced in the collisions. Compared to the HERA or to the Tevatron detectors, it extends the measurement region covering the soft remnants of electrons, nucleons and nuclei. It redefines the conventional detector-machine interface.

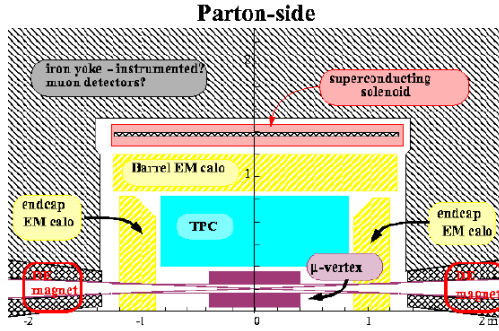


Figure 2. The parton side of the generic detector

The first attempt to design such a detector has been presented at the Yale workshop [4]. The following criteria were imposed for this initial trial:

- The detector should be common for ep, eA, pp and pA collisions to study both the hard scattering of partons and the beam particle dependent medium effects.
- It should allow for the reconstruction of complete ep and eA events (covering the proton fragmentation region in the pp and the pA collisions, a provision for adding a muon detection system and a charged kaon identification system, remains open at this design stage).

- The beam crossing optics should minimize the clash with the existing RHIC interaction region optics.
- The existing RHIC magnets should be used, as much as they can be useful, in the spectrometer design.
- The electron insertion should provide a functionality of the spin rotator.
- The design should remain invariant of the choice of Ring-Ring versus Linac-Ring collisions.
- The detector should provide precise luminosity monitoring and good experimental control of radiative corrections for electron induced reactions.

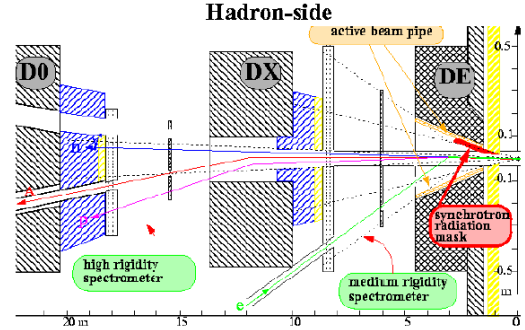


Figure 3. The hadron side of the generic detector

The general layout of the detector geometry is shown in Fig. 1. It is symmetric around the collision axis with a central detector and two symmetric arms along the  $z$  direction. For the ep and eA collisions the instrumentation of the left arm, called hereafter the hadron side, and the right arm, called hereafter the electron side is initially asymmetric. It would be possible to upgrade such a detector for pp and pA collisions by adding the detector elements of the hadron side to the electron side.

The function of the central detector, shown in Fig. 2, is to determine the kinematics of hard processes by measuring the momenta and angles of outgoing leptons quark and gluon jets. The barrel is a TPC backed by a gas EM calorimeter inside a super-conducting coil. Both end-cups are SPACAL calorimeters. This is a minimal set up for the parton detector.

The proton (nucleus) fragmentation region is covered by the high rigidity and medium rigidity spectrometers shown in Fig. 3. The function of these spectrometers is to measure wounded and evaporated nucleons, nuclear fragments as well as other low-angle particles. The spectrometers involve the tracking modules and calorimeter stations and use, in measuring the momentum of charged particles, the magnetic field of the D0 and DE magnets.

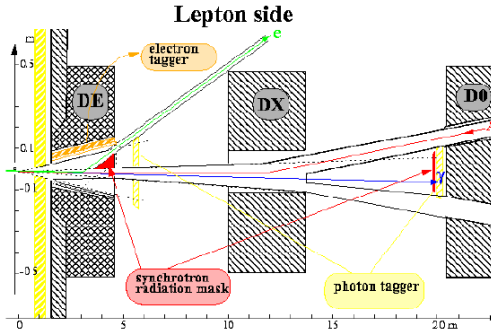


Figure 4. The lepton side of the generic detector

The detection system in the electron fragmentation region, shown in Fig. 4, defines the minimal setup for the electron-nucleon (electron-nucleus) collisions. It provides a precise tagging of DIS and photo-production processes and measures the low angle photons for luminosity measurement and provides experimental means to control the electro-magnetic radiative corrections.

The spectrometer optics combines several functions. The 2.3 Tm bending power of the DE magnet distributed over 3 meters is 3 times higher

than the inflection field at DESY. It produces a deflection angle of 70 mrad for 10 GeV beam and is designed to rotate the spin vector by 90 degrees (this constraint is only of importance for a circular electron machine). With this geometry the electron beam bypasses the DX magnet entirely, thus uncoupling the electron beam optics from the ion beam optics. The geometry of the present design have, unquestionable advantages with respect to that of the HERA collider. Owing to smaller electron beam energy the eRHIC interaction region can tolerate 10 times higher electron beam current than HERA i.e. 600 mA. Using low emittance electron-linac beam a 100 fold increase of luminosity can be achieved while keeping the synchrotron radiation at tolerable level.

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